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DETECTION OF BALD EAGLES DURING AERIAL SURVEYS IN PRINCE WILLIAM SOUND, ALASKA

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Abstract.—Bald Eagles (*Haliaeetus leucocephalus*) are often counted by aerial surveys but, because some birds are not detected, this approach provides only an index to population size. We estimated detection rates for Bald Eagles during fixed-wing aerial surveys in Prince William Sound, Alaska to extrapolate the index to an estimate of the total population of Bald Eagles in Prince William Sound. Using a modified Petersen estimate and independent front and back seat observers, we estimated that we detected 79% and 51% of observable adult and immature eagles, respectively. Using data from a radio-telemetry study, we also estimated that 21% of adult eagles were unavailable for detection because they were in locations not visible to airborne observers following the shoreline at tree-top level. Combining both perception and availability biases, 62% of adult eagles was seen (visibility correction factor of 1.6). Detection rates were similar between a Cessna 185 and a turbine DeHavilland Beaver aircraft. We believe these detection rates are generally applicable to Bald Eagles in the coniferous coastal forests from Washington to Alaska, but encourage collection of similar data in future surveys to enable estimates of site-specific detection rates.

Key Words: *Bald Eagle;* Haliaeetus leucocephalus; *aerial survey; detection rates; visibility bias; Prince William Sound, Alaska.*

Detección de águilas calvas durante los monitoreos aéreos en Prince William Sound, Alaska

Resumen.—Las águilas calvas (*Haliaeetus leucocephalus*) son usualmente contadas en monitoreos aéreos, debido a que algunos individuos no son detectados, este enfoque provee tan sólo un índice del tamaño poblacional. Estimamos las tasas de detección de águilas calvas durante monitoreos aéreos en Prince William Sound. Utilizamos un estimativo modificado de Petersen con observadores independientes adelante y atras, estimamos que detectamos 79% y 51% de los adultos observables y de los juveniles respectivamente. Mediante la utilización de datos y de un estudio de telemetría, estimamos tambien que el 21 % de las águilas adultas no pudieron ser detectadas debido a que se encontraban en sitios no visibles a los observadores al seguir la línea de costa y el dosel de los árboles. Al combinar ambos, los sesgos de percepción y disponibilidad, 62% de las águilas fueron detectadas (factor de corrección de visibilidad de 1.6). Las tasas de detección fueron similares entre un Cessna 185 y un avión De-Havilland Beaver de turbina. Creemos que las tasas de detección son en general aplicables a las águilas calvas en los bosques de coníferas costeras desde Washington a Alaska, pero recomendamos la recolección de datos similares en monitoreos futuros con el fin de estimar tasas de detección en sitios específicos.

[Traducción de César Márquez]

Bald Eagle (*Haliaeetus leucocephalus*) populations are often censused using aerial surveys (King et al. 1972, Hodges et al. 1984, Fuller and Mosher 1987). Adult Bald Eagles have conspicuous white heads and tails and typically perch in prominent positions where they are easily seen. Immature eagles have less conspicuous plumage, select less prominent perch sites (Hancock 1964) and are relatively difficult to see or accurately count during aerial surveys. Because some eagles are missed or impossible to see, population surveys provide indexes that represent a constant but unknown fraction of the total population. Indices are seldom free of visibility bias and usually underestimate true population size. Although indices are usually adequate for monitoring population trends, estimates of total population size are sometimes needed for modeling population dynamics, estimating the probability of extinction, or evaluating the effects of catastrophic events. Survey-specific visibility correction factors can help standardize for biases that vary among surveys or over time, and enable better comparisons of numbers among populations with different detection rates or that are surveyed using different methods. Consequently, visibility-adjusted indexes can, in some instances, facilitate and improve management decisions.

The detectability of animals to airborne observers may be influenced by environmental conditions (e.g., time of day, weather, snow cover, topography, season, habitat), observers (e.g., level of ability, experience, fatigue), aircraft factors (e.g., type of aircraft, speed, altitude, window size and position) and biological factors (e.g., animal behavior, age and sex of animal, breeding status) (King et al. 1972, Grier 1977, Leighton et al. 1979, Grier et al. 1981, Hodges and King 1982, Kochert 1986, Fuller and Mosher 1987, Pollock and Kendall 1987). Marsh and Sinclair (1989) described two categories of missed animals: those that are potentially available to observers but are not seen (perception bias) and those that are not available to observers because they are concealed by vegetation, other animals, turbid water, topographic features, or temporarily absent (availability bias).

Using data from a range of wildlife surveys, Caughley (1977) showed that 30–60% of animals are often missed. Estimates of detectability of eagles are generally lacking, but, based on a combination of quantitative and qualitative methods, Hancock (1964) concluded that adult Bald Eagles can be undercounted by <10–15% and immatures by 20–35% during winter aerial surveys in coastal British Columbia. Buehler et al. (1991), on Chesapeake Bay, Maryland, estimated that they saw 31–75% of detectable eagles and that 31–49% were off aerial survey routes when flown throughout the year. Hodges (pers. comm.) recommended using a correction factor of 2.5 when estimating number of eagles missed by observers, based on simulations with hypothetical detection probability distributions.

In this study, we used a two-sample capture-recapture (Lincoln-Petersen) estimator (Seber 1973, Magnussen et al. 1978) using two independent observers recording simultaneously to estimate detection rate of eagles in Prince William Sound, Alaska. The paired observer method estimated only perception bias and did not account for availability bias (eagles with zero probability of being seen, such as those perched in areas off the survey route or birds soaring at high altitude). We estimated availability bias using a sample of radio-tagged adult eagles (Bowman et al. 1993) and combined it with estimates of perception bias to estimate an overall visibility correction factor.

STUDY AREA

Prince William Sound is located in southcentral, coastal Alaska and encompasses about 39 000 km^2 including 4800 km of shoreline. The coastline is complex with many islands, particularly in the western Sound. Temperate rainforest dominated by Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) grows to an elevation of about 500 m. It is relatively uniform in species composition but varies in structure, density, interspersion of forest and clearings and age. The area we surveyed included all islands in Prince William Sound and randomly selected plots on mainland areas. Only shorelines were searched; we did not survey river valleys or inland areas. Snow was present on the ground in some areas when we surveyed.

There are about 6000 eagles in Prince William Sound, with nest densities as high as 0.5/km of shoreline (Bowman et al. 1997). Bald Eagles nest exclusively in trees in Prince William Sound and incubation begins in mid- to late-April. As is typical of coastal nesting Bald Eagles (Hancock 1964, Hodges and Robards 1982), nearly all nests were <200 m of the shoreline.

METHODS

The survey was intended to provide an index of the resident adult eagle population, and therefore was flown early in the nesting period presumably when migrant eagles had left the area for their respective breeding areas (e.g., along inland rivers) and movements of local breeders were limited by nesting activity. We used Cessna 185 and turbine DeHavilland Beaver aircraft on amphibious floats. Survey methodology followed Hodges et al (1984).

We searched shorelines from an altitude of 50–100 m at an airspeed of about 160 km/hr, with most shorelines (and eagles) on the right side of the aircraft. The front right seat observer recorded his and the pilot's observations from either side of the aircraft on continuously-running cassette tapes and on USGS 1:63 360 scale topographic maps. The back seat observer counted eagles only on the right side of the aircraft, and simultaneously recorded observations on cassette tapes. The back seat observer was audibly (headsets) and visually (barrier) separated from the front seat observers. We recorded observations for 3–15 min periods and synchronized our cassette recordings. We noted general weather conditions encountered during each recording session.

We spent one day flying before we began our survey to develop our search image and to refine the protocol for recording observations on tape. We did not use data from that day in this analysis.

Tapes were transcribed using a computer data entry program (Butler et al. 1995) to determine the time from the start of each recording period for each observation (as determined by the proportion of elapsed time from start of transect). We matched right side observations made by the front and rear seat observers using the category designation (age, behavior and relative sightability), time elapsed from the start of the recording session and observers' descriptions of eagles (e.g., distance from shore, elevation, type of tree, position in tree). Left side observations were excluded because they were not available to the back seat observer.

The percentage of birds seen by front seat observers (perception bias) was estimated by:

$$\frac{n_2}{N} = \frac{m_2}{n_1}$$

where, N = total number of eagles visible (population size), n_1 = number of eagles seen by back seat observer (marked sample), n_2 = number seen by front seat observers (recaptured sample), m_2 = number seen by both the back and front seat observers (number in recaptured sample that were marked).

Estimates of detectability applied to the combined efforts of pilots and front seat observer because front seat observer and pilots combined sightings. Variance of the estimate was calculated for a proportion with binomial distribution according to Fowler and Cohen (1986).

Assumptions of the Petersen estimator are that sightings of different objects by different observers occur independently, the population is constant in size during the observation period, there are no errors in determining which objects are seen by either one, or both, of the observers, and each object has the same probability of being seen by any one observer (although observers may differ in their detection such as when one observer's window affords a better view than the other's). We probably met the first assumption because observers were effectively audibly and visually isolated from each other and, for the most part, eagles were sparsely distributed and sightings occurred independently (although paired eagles perched nearby one another may have influenced detection of their mate). The population was constant in size because observations by the two observers were made simultaneously. We are confident that we reasonably met the third assumption because most adult eagles occupied territories, often with considerable distances between them, and because we made notes on behavior or location that aided us in matching observations. We recognized that eagles were likely to have different sighting probabilities related to their behavior, location, plumage and habitat use so we addressed the assumption of equal probability of detection by dividing the population of eagles into subsets with relatively similar detectability. We estimated detection rates independently for each subset but did not report detection rates for categories with fewer than seven matched observations because estimates can be biased with <7 matched observations (Seber 1973).

A weighted average detection for the subdivided population of adult eagles was calculated as:

$$p = \frac{\sum n_{2_i}}{\sum \hat{N}_i}$$

We used the following categories for observations: (1) adult perched, easy to see; (2) adult perched, moderately difficult to see, (3) adult perched, very difficult to see; (4) adult flying (below wing level); (5) adult soaring (above wing level); (6) adult incubating; (7) immature perched; and (8) immature flying. These categories were intended to subset the population into groups with relatively similar detectability. Although we recorded three categories of perched adults (easy, moderate and very difficult), there was enough subjectivity in these categories that, to facilitate matching, we reduced it to two categories. If either observer called a matched bird easy to see, it was tallied in the easy category. All other combinations of categories (e.g., moderate/difficult, moderate/moderate, difficult/difficult) were included in the difficult category.

We estimated availability bias by observing 38 radio-tagged adult eagles during the incubation period (timing similar to population surveys), which we relocated from fixed-wing aircraft in 1990–91. When we visually observed a radio-tagged eagle, we noted bird activity (e.g., soaring, perched, incubating) and location (e.g., tree, beach, elevation or altitude), and noted whether the eagle, for whatever reason, would have been impossible to see (i.e., availability bias) during a typical population survey focused primarily on shoreline habitats at lower elevations. Radio-tagged eagles included both males and females; all were believed to be breeding birds. Standard error of the estimated proportion impossible to see was estimated for a proportion with binomial distribution according to Fowler and Cohen (1986).

We also recorded weather conditions during telemetry flights, noting the extent and height of cloud cover and the presence of fog or rain. The range of weather conditions encountered during telemetry flights was similar to weather conditions during population surveys. Rainy or windy days were avoided while surveying because flying conditions are impossible or unsafe.

RESULTS

Detection of eagles was similar from both aircraft when flown under similar weather conditions (Table 1). Therefore, we pooled data for both planes. Detection rates varied among subsets. Perched adults (detectability perched easy = 0.935, SE = 0.01; detectability perched difficult = 0.561, SE = 0.05) were more likely to be seen than perched immatures (0.419, SE = 0.09), but detectability of flying adults (0.815, SE = 0.07) was similar to flying immatures (0.833, SE = 0.11). The overall weighted perception bias (perched + flying) was 0.790 (SE = 0.018) for adult eagles and 0.512 (SE = 0.036) for immature eagles. Perception bias using an uncategorized approach (i.e., pooling categories only by age) was 0.85 for adults and 0.54 for immatures.

Of 38 radio-tagged adult eagles located during the incubation period, we estimated 21% (8 of 38) were impossible to see because they were soaring

Table 1. Detection probabilities of Bald Eagles during aerial surveys in Prince William Sound, Alaska, 1995.

			Detection Probability (SE[a]) [n[b]]					
Date	Aircraft	Environmental Conditions	Adult Perched, Easy	Adult Perched, Difficult	Adult Flying[c]	Adult Incubating	Immature Perched	Immature Flying[c]
21 April	Cessna 185	High overcast, calm	0.945 (0.020) [139]	0.667 (0.086) [48]	NA[d] [6]	NA [0]	NA [7]	NA [1]
23 April	Turbine Beaver	Cloudy/ broken skies, fog patches	0.968 (0.016) [135]	0.684 (0.075) [62]	0.778 (0.139) [16]	NA [3]	0.615 (0.135) [14]	NA [9]
26 April	Turbine Beaver	Sunny, calm	0.917 (0.022) [172]	0.500 (0.086) [56]	0.778 (0.139) (12]	NA [14]	NA [8]	NA [7]
27 April	Turbine Beaver	Sunny, calm, extensive snow cover	0.891 (0.042) [65]	0.083 (0.080) [12]	NA [7]	NA [10]	NA [1]	NA [0]
All data pooled			0.935 (0.011) [511]	0.561 (0.047) [178]	0.815 (0.075) [41]	0.591 (0.105) [27]	0.419 (0.089) [30]	0.833 (0.108) [17]

[a] Standard error.
[b] Number of birds seen by front seat observers.
[c] Indicates birds flying at or below aircraft wing level (i.e., not soaring at high altitude).
[d] Insufficient number (<7) of matched observations to estimate detection.

high, perched somewhere not visible from a shoreline flight path, or incubating in a nest impossible to see from an aircraft.

Cumulative percent seen (perception bias * availability bias) was 0.623 (SE = 0.055). This was equivalent to a visibility correction factor of 1.6 (SE = 0.14) for adult eagles.

DISCUSSION

The 1995 index for Prince William Sound, which combined an island census and estimate from random plots on mainland, was 2641 adult eagles and an estimated 26.5% of the population (based on age ratios of flying eagles) were immatures (Bowman et al. 1997). Corrected for visibility, an estimated 4239 adult and 1528 immature (total of 5767) eagles resided in Prince William Sound in April 1995.

For most aerial surveys of Bald Eagles in Alaska and British Columbia, the age ratio of flying eagles has been used to represent the age ratio of eagles in the study area. This assumes that adults and immatures are equally likely to be flying (Hancock 1964, Hodges et al. 1984), although this assumption has never been tested. Using the age ratio of flying eagles, the proportion of immatures in the Prince William Sound population averaged 29% during 1989–95 surveys and did not vary significantly among years (Bowman et al. 1997). By adjusting counts for age-specific detection rates estimated during this survey, we estimated that only 8.4% of the population we surveyed were immatures. Therefore, our data suggested that immatures are more likely to be flying than adults, and that estimates based on age ratios of flying birds overestimated the proportion of immatures, and thus total population size. Intuitively, this seemed likely for several reasons. Many adults were incubating during the time of the survey and were less likely to be flying. Immatures may also have had different foraging strategies and flew more frequently to find adequate resources to survive (Gerrard and Bortolotti 1988).

Although inadequate number of replicates precluded a statistical assessment of specific factors influencing detection rates, we attributed the lower detection rates during the last two days of the survey to sunny weather as well as extensive snow cover encountered in mainland areas of western Prince William Sound on the last day of the survey. Throughout the survey, we had higher detectability under cloudy skies and reduced detectability under sunny conditions. Under sunny skies, reflections and glare from the water and aircraft windows impaired visibility. Snow cover decreased contrast between white plumage and forest. Observer fatigue, due to cumulative effects of flying surveys several consecutive days, also could have been a confounding factor, although we believe it was insignificant relative to weather effects.

Our estimates of perception bias were similar to those made by Buehler et al. (1991) in Chesapeake Bay during the early nesting period ($\bar{x}$ = 71.2% for January–March). Buehler et al. (1991) also estimated that about 40% of eagles were off survey routes and their estimated total correction factor (detectability and availability biases combined) of 2.38 was higher than ours (1.6) for the early nesting period. Hodges (pers. comm.) suggested a correction factor of 2.5 be applied to the number of missed (missed = estimated total population − number detected) observable eagles based on simulations with hypothetical detectability distributions. His result using simulations was roughly consistent with our empirical estimate of 0.79 detectability for adult eagles. Hodges found that the correction was robust to small variations in detectability distributions. Similarly, our empirical data comparing categorized and uncategorized estimates suggested that relative bias (bias/parameter) was 6–8%. Detection rates will be biased higher in populations with a high proportion of easily-detected animals versus a population with a high proportion of animals difficult to see (Seber 1973).

Our estimate for availability bias (i.e., that estimated using radio-tagged birds) was somewhat suspect because the sample of relocated eagles during the incubation period was small, we have no similar data for immature eagles, and radio-tagged adults included a disproportionate number of territorial birds, which were presumably more likely to be seen than nonterritorial eagles because they were associated with nest sites. Although our estimate gave an idea of the magnitude of availability bias in Prince William Sound, the applicability of our estimate to other areas warrants further investigation, and we encourage researchers with radio-tagged birds to estimate site specific and aircraft specific (e.g., fixed-wing vs. helicopter) detectability. Buehler et al.'s (1991) estimate of 40% off survey route is not directly comparable with our estimate of 21% due to differences in how the estimate was derived and because their sample included a higher proportion of nonbreeding adults, which are more likely to range farther than territorial nesting birds. Nevertheless, their estimate and ours provide some insight into the magnitude of variation among areas. The proportion of eagles not observable certainly varies by geographic area because of differences in topography, climate, vegetation, food sources and between marine and inland areas.

Detection rates should apply to past surveys in forested areas of coastal Alaska because aircraft, techniques and observer skill were similar among surveys. Further, we believe these detection rates would be useful for surveys in similar habitats (e.g., coastal coniferous forests in northwestern North America) where detection rates are unknown and researchers wish to make some estimate of total population size from available indexes.

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